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To Dr. W.R. Effer
Manager
Environmental Studies and
Assessments

HATCHING TIME OF ROUND WHITEFISH EGGS AND LARVAL PREFERENCES FOR SUBSTRATE AND DEPTH

R.S. McKinley

The objective of this study was to determine where round whitefish larvae reside following hatching. Round whitefish eggs began to hatch at an average of 298 degree days. Larvae associated with the bottom, preferred a sand substrate over gravel or cobble, particularly during lighted conditions. Larvae also preferred the bottom of a 135 cm test column as opposed to the surface.

INTRODUCTION

At the request of Environmental Studies and Assessments Department, a laboratory study was conducted to determine: 1) the time and temperature of round whitefish egg hatch, and 2) observe the behaviour of round whitefish larvae relative to depth and substrate. The intention of this work was to improve methods for studying the round whitefish population in Lake Ontario by providing information on when, where and how larvae may be efficiently sampled.

MATERIALS AND METHODS

Adult round whitefish, *Prosopium cylindraceum*, were collected off Thickson Point, Lake Ontario on December 1, 1981. Surface temperature was 4.5°C. Eggs were dry spawned, water hardened for one hour and transported back to the Research Laboratory in 5°C lake water.

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740634-103-492	837.321PIC	February 17, 1983	83-57-K

Egg Incubation

Eggs were incubated in the egg incubation apparatus described in Ontario Hydro Research Division Report 76-499-K (Figure 1) until the early development mortality peak reported in Ontario Hydro Research Division Report 80-140-K, was passed. Two hundred and fifty eggs were then suspended on screens in nine separate 20 L flow-through aquaria each with a flow rate of 800 mL/min. The bottom of three of the nine tanks was covered with sand (0.3 - 0.5 mm diameter), three with gravel (10 - 15 mm) and three with cobble (60 - 90 mm). These substrates were selected on the basis of being representative of three predominant nearshore Lake Ontario substrates (Ontario Hydro Research Division Report 79-165-K).

All tanks were maintained under a simulated natural photoperiod using overhead incandescent lighting and ambient Lake Ontario water temperatures. Daily mean water temperatures were determined from the Oshawa water supply intake pump which draws water from a submerged intake 1600 m offshore at 12 m and the Ajax water supply intake well which obtains water from a submerged intake 643 m offshore at 10 m. The temperature regime in each incubation tank simulated nearshore temperatures recorded in the vicinity of Ajax and Oshawa during the fall to spring incubation period (Appendix 1). Since simulating absolute temperature fluctuations was not possible, attempts were made to maintain a similar number of degree days between the incubation tanks and nearshore temperatures.

Mean daily temperatures among the three incubation tanks differed by less than 1.0°C and number of degree days for each development block was similar for eggs in each of the three incubation tanks. Temperature and time at which hatch occurred were recorded and used in the models for round whitefish development outlined in Ontario Hydro Research Division Report 80-140-K. A comparison between observed hatch and time of hatch predicted by the model was made.

Substrate Preference

At stage 20 (Brooke, 1975) or near hatch, 150 eggs from the substrate incubation tanks were transferred to four experimental aquaria, each with a capacity of 182 L and a water flow rate of 1 L/min. The bottom of each tank was systematically divided into the three substrate types. The 150 eggs were equally divided, placed on screens and suspended 2.5 cm off the bottom of each substrate type (Figure 2). Therefore, eggs previously incubated over each substrate were exposed to all other substrates upon hatching. The fourth tank contained eggs that were previously incubated on an artificial substrate (screen) and served as a control.

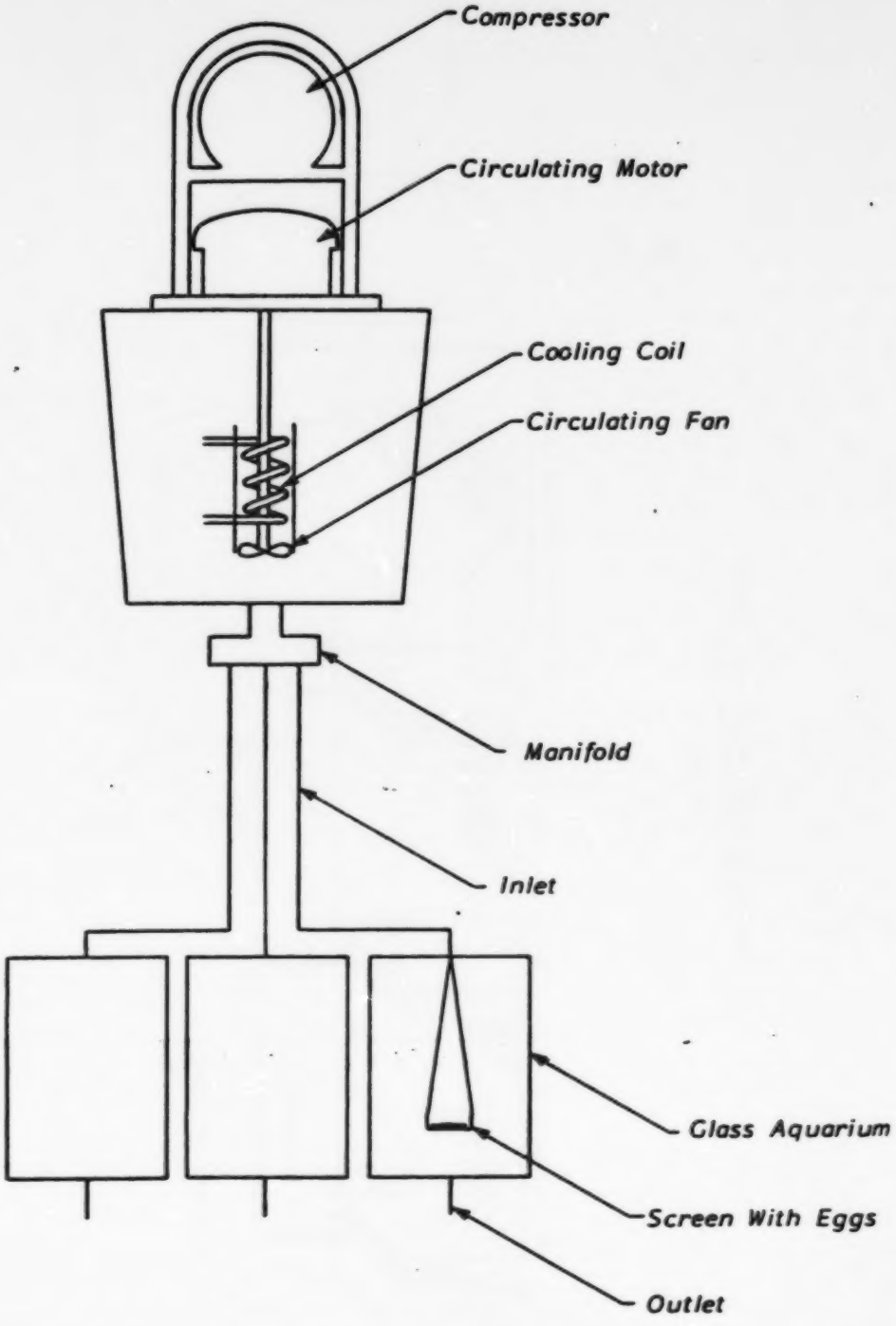

FIGURE 1

AMBIENT TEMPERATURE
FISH EGG INCUBATION SYSTEM

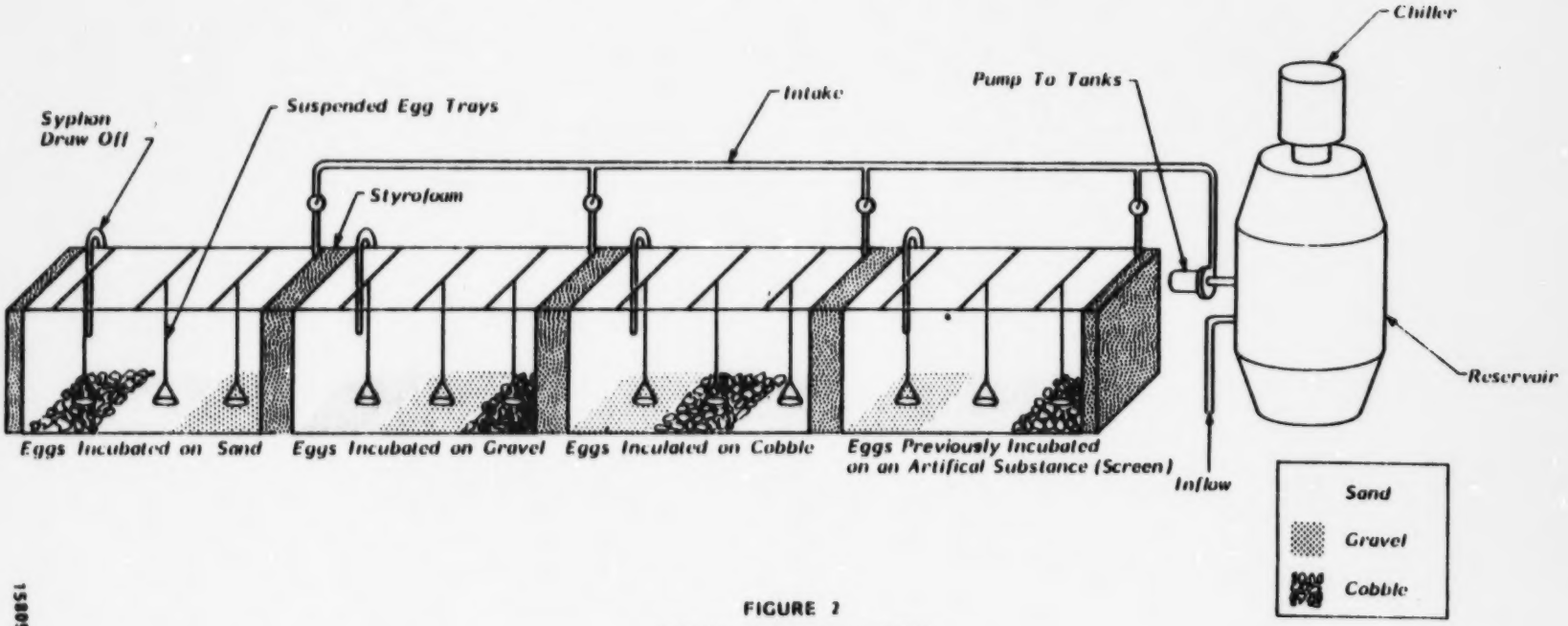

FIGURE 1

LARVAL ROUND WHITEFISH
SUBSTRATE PREFERENCE TEST TANKS

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Following hatch, position of larvae in the tanks was observed three times a day, at maximum light intensity 7.0 - 8.0 lx, minimum light intensity ~1.0 lx and in darkness <1.0 lx for three weeks. The total number of larvae on each substrate type was expressed as an average per cent of total observed on the bottom. Any unhatched or dead eggs were also noted. Again, water temperature and photoperiod regimes in the laboratory simulated ambient Lake Ontario conditions. Analysis used to determine substrate preference only included the larvae observed resting on the three substrates during each of the three observation periods.

Depth Preference

A static water plexiglass column (14.0 cm dia x 135.0 cm high) was constructed and surrounded by an outside water jacket (30.0 cm dia x 200 cm high) (Figure 3). A continuous water flow of 2 L/min was supplied to the outside jacket to maintain the inside column at ambient Lake Ontario water temperatures. The column was also maintained under a simulated natural photoperiod.

At stage 20, 50 eggs were suspended on a screen 10 cm from the bottom. Following hatching, the depth at which larval fish were swimming in the column was recorded three times a day (maximum and minimum light intensity and darkness) for fourteen days.

The larvae used for the substrate preference tests ranged from 14 mm (total length) at hatch to 16.5 mm at the end of tests (16 days). Yolk sac was completely absorbed by day six (Appendix 5).

RESULTS

Egg Incubation

Egg incubation was begun on December 3 at 5.0°C. Temperatures declined to near 1.0°C by the end of December then rose to 5.5°C by the end of April.

First hatch occurred on day 123 (April 5) at a temperature of 5.6°C at an average of 298 degree days. Complete hatch occurred on day 131 (April 13).

A comparison of the development periods for the three blocks of embryonic development (Appendix 3) between observed and predicted results is shown in Figure 4. Times observed for the completion of Blocks 1, 2 and 3 were 29, 102 and 131 days respectively, whereas times predicted by the models were 24, 94 and 131 days respectively. Thus observed and predicted times from fertilization to hatch were equivalent. However, observed times to completion of Blocks 1 and 2 were somewhat longer than that indicated by the predictive models.

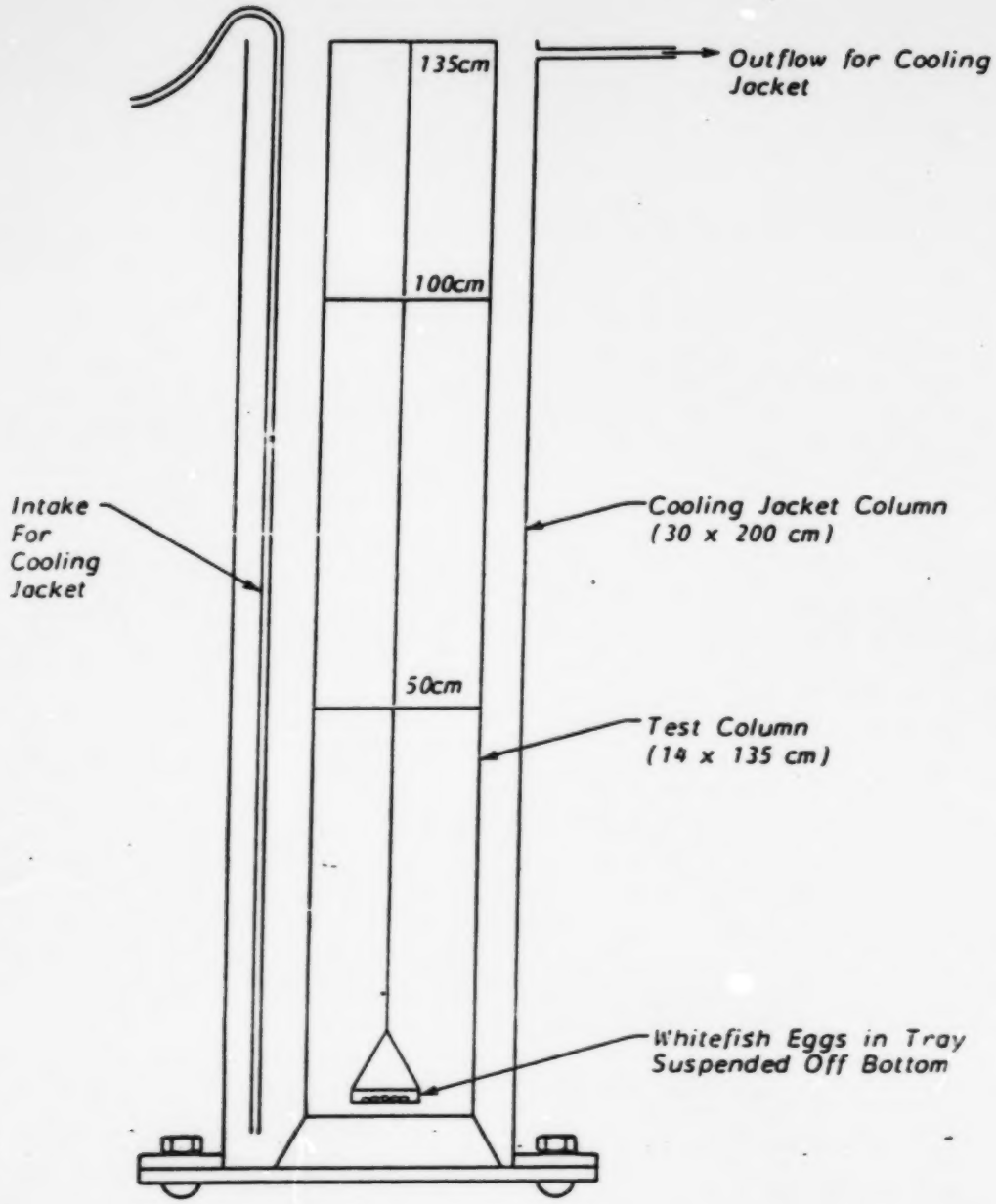

FIGURE 3

LARVAL ROUND WHITEFISH
DEPTH PREFERENCE TEST COLUMN

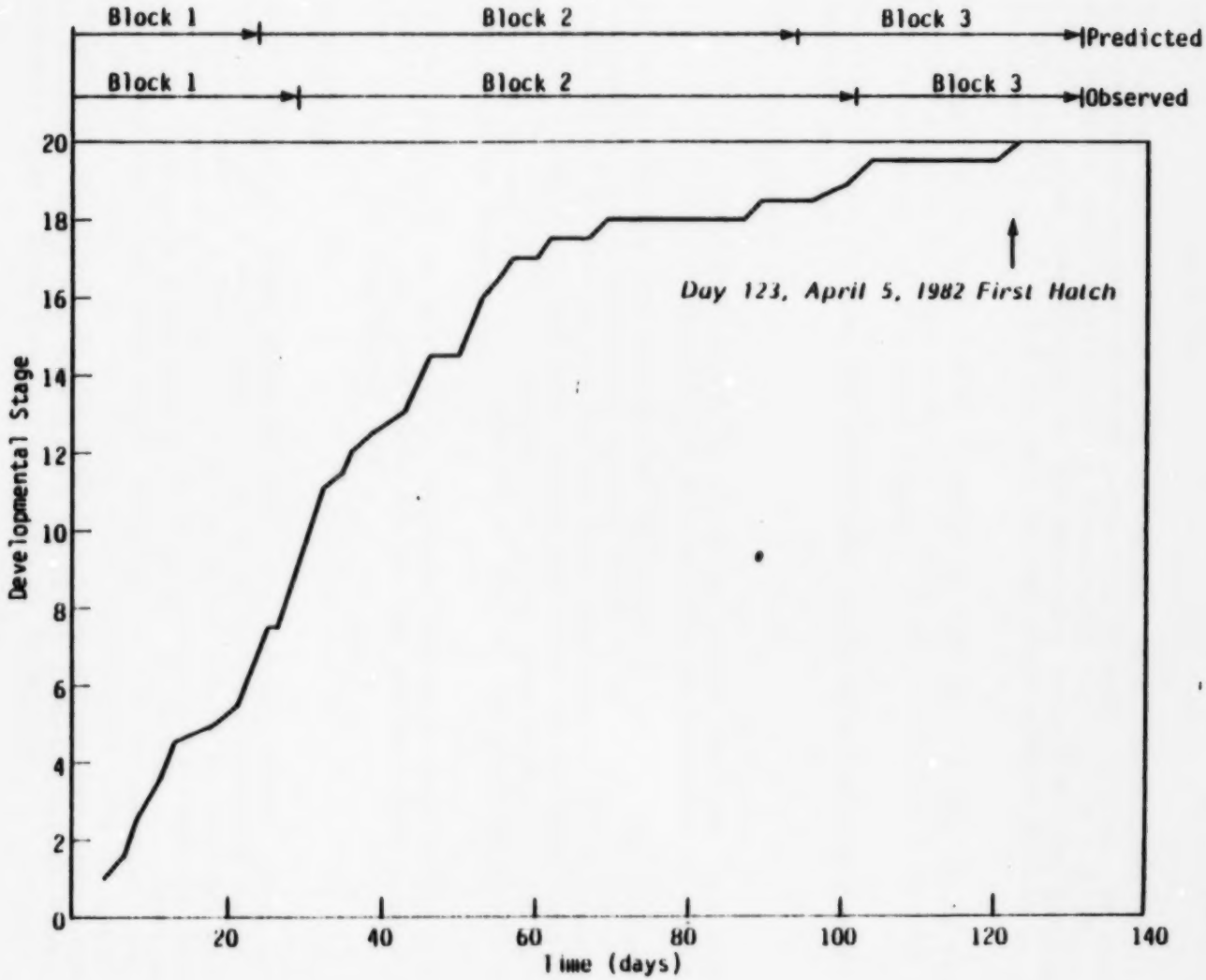

FIGURE 4

ROUND WHITEFISH - SPAWNED 1 DECEMBER 1981 (GROUP 1)
DEVELOPMENTAL STAGES: OBSERVED & PREDICTED

Substrate Preference

The substrate preferred by larvae, regardless of size and onset of exogenous feeding or loss of yolk sac (day 6), was sand (Figure 5). Round whitefish incubated on gravel or cobble were more strongly attracted to sand than those incubated on sand ($F = 16.2_{6,2164}$ $p<0.05$).

The consistent preference by larvae for sand, regardless of light and previous incubation conditions (ie on sand, gravel, or cobble) did however vary significantly throughout the day ($F = 8.92_{4,216}$, $p<0.05$). Sand was chosen to the greatest extent during maximum light levels (7.0 - 8.0 lx) and to the least extent during darkness (<1.0 lx).

The majority of fish (<50%) however during any of the three observation periods were swimming in the upper third (30 cm off the substrates) of all three tanks.

Larval survival during the substrate preference tests was one hundred per cent.

Depth Preference

Difficulty was experienced in counting larvae through the column so values shown in Appendix 5 should only be regarded as estimates.

Larvae preferred the bottom ten centimeters of the test column throughout the experimental period (Figure 6). Regardless of light conditions, 80-90% of the larvae were observed in the bottom third of the column. Seldom were larvae observed in mid-water and only up to 10%, particularly during darkness, were found at the surface. Whether or not the swim bladders of any of the fish were inflated could not be determined.

Larval survival by the end of the test was less than fifty per cent. Larval mortality may have been due to the static water condition used during the preference test.

DISCUSSION

Round whitefish eggs began to hatch in the laboratory after an average of 298 degree days. Reference to only absolute water temperatures as a means to predict hatch should be avoided as evident from the variability in water temperature observed between the two locations used during this study (Appendix 1). However, it should be noted that water temperature (as degree days) may not be the only factor in the field which determines time of hatch. Mechanical agitation of the eggs via wave action has been suggested as a factor which may accelerate hatch of Lake whitefish eggs (Ontario Hydro Research Division Report 79-521-K).

Results of this study indicated that larvae associated with the bottom of our experimental tanks consistently preferred a sand substrate. It should be noted however, that the majority of larvae

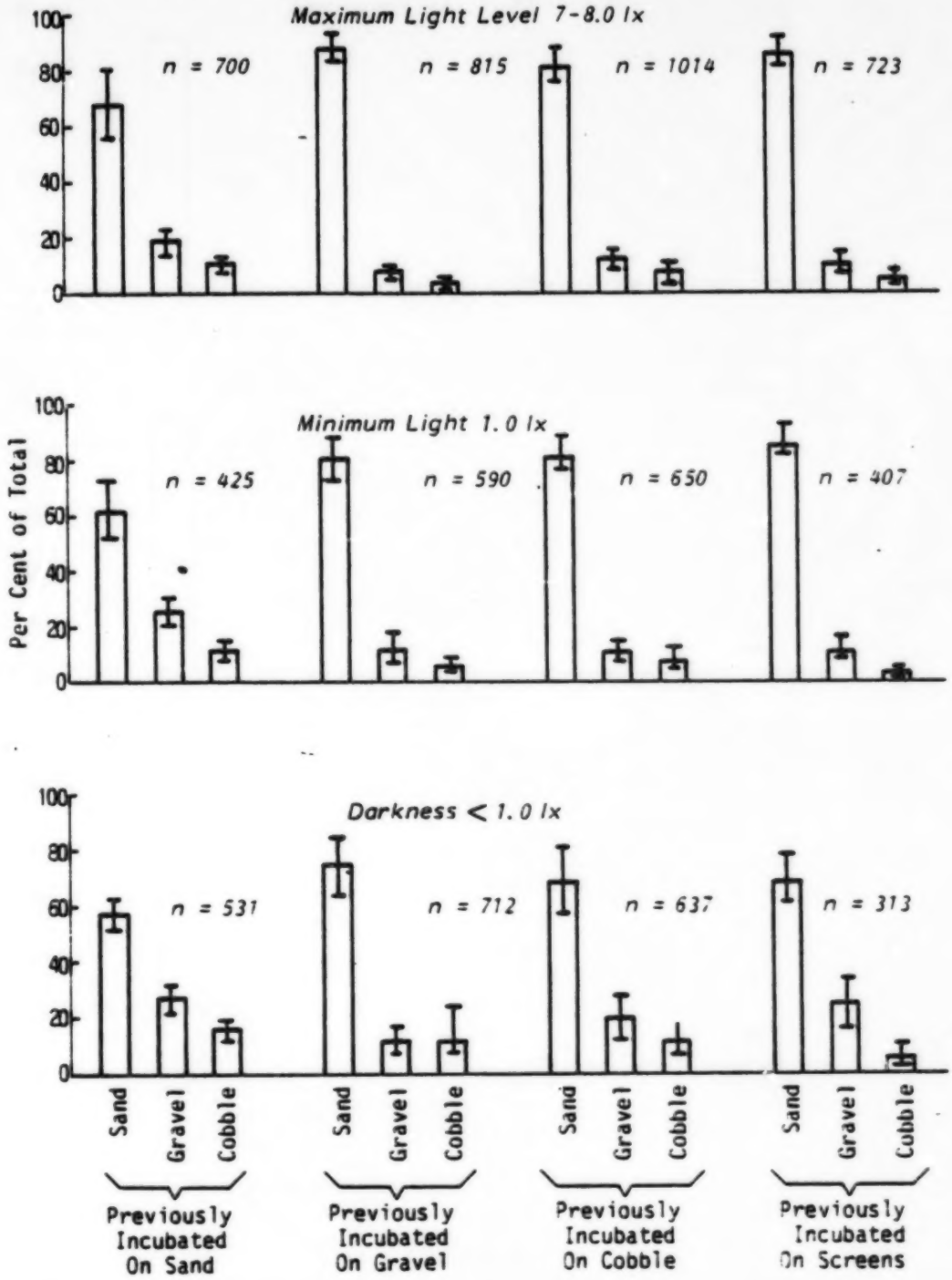

FIGURE 5

SUBSTRATE PREFERENCE OF LARVAL ROUND WHITEFISH UNDER THREE LIGHT REGIMES. VALUES ARE EXPRESSED AS AN AVERAGE PER CENT OF TOTAL NUMBER OBSERVED ON THE BOTTOM ± S.D. THE NUMBER OF LARVAE OBSERVED FOR EACH PREVIOUS INDUBATION HISTORY IS INDICATED ABOVE THE RESPECTIVE HISTOGRAMS

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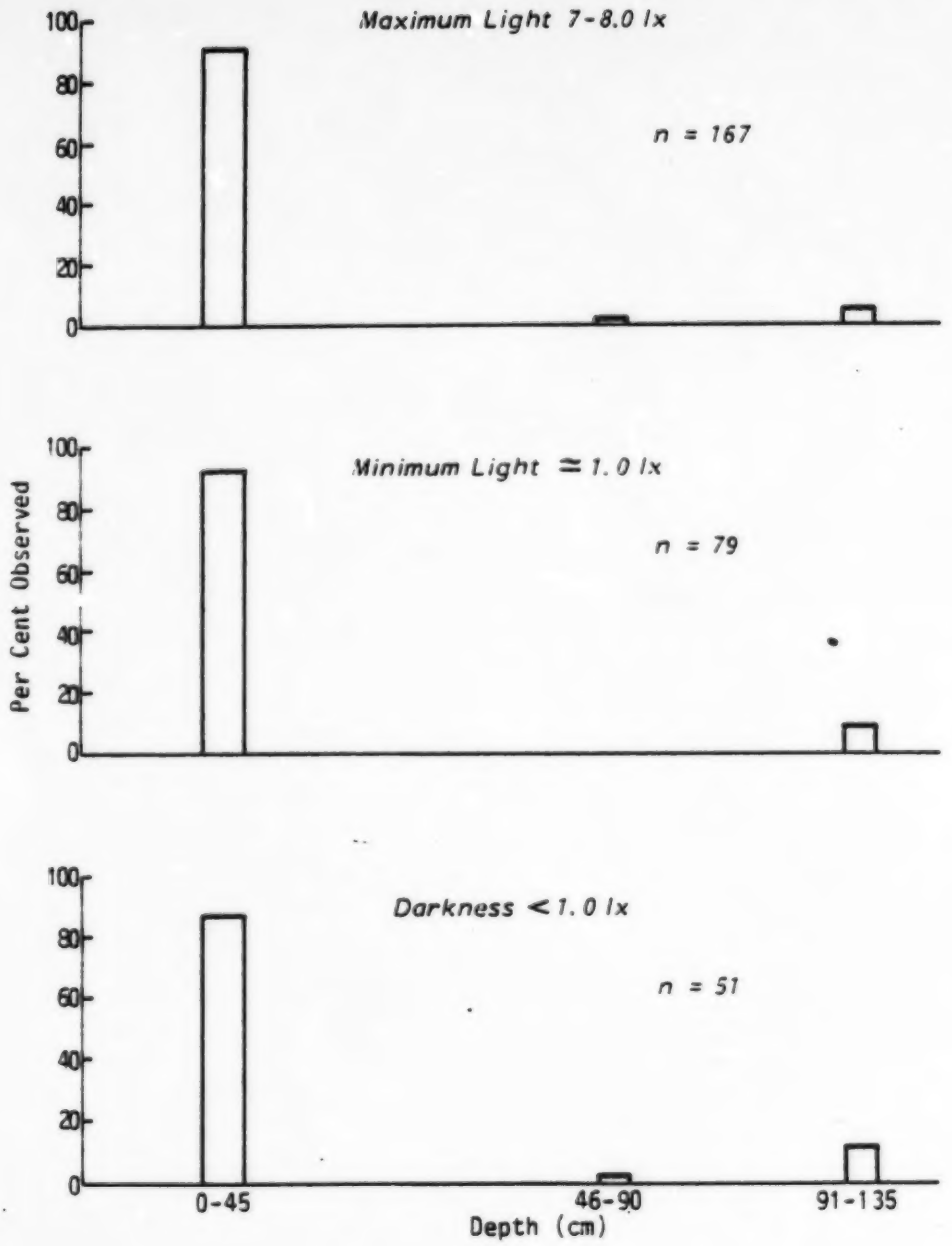

FIGURE 6

DEPTH PREFERENCE OF LARVAL ROUND WHITEFISH UNDER THREE LIGHT REGIMES. VALUES ARE EXPRESSED AS A PER CENT OF TOTAL NUMBER OBSERVED AT THE VARIOUS DEPTHS THE NUMBER OF LARVAE OBSERVED AT EACH DEPTH IS INDICATED ABOVE THE RESPECTIVE HISTOGRAM

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during any of the three observation periods were swimming rather than resting on the bottom.

The consistent preference by resting larvae, particularly during lighted conditions, suggests a visual rather than, or in addition to, a tactile response. Reduced visual discrimination by those larvae during darkness, like larvae of many teleost species, may be due to the pure cone retina or cells which mediate vision under high light levels. Rods or cells which mediate vision under low light levels appear well after hatching and often not until the juvenile stage (Sandy and Blaxter, 1980).

The preference for sand may be effective for camouflage since larvae were more difficult to detect on sand than on the other surfaces. The contrast between fish and substrate on the remaining substrates, particularly cobble, was more evident.

In a qualitative examination of depth preference, round whitefish larvae preferred to remain on or near the bottom of a 135 cm test column, rising occasionally to the surface of the column throughout the course of the experiment. Similar observations of newly hatched larvae have been made in a previous laboratory study which suggested that the large yolk sac may inhibit mobility (Ontario Hydro Research Division Report 80-140-K). It is interesting to note, however, that the bottom was still preferred by the larvae whose yolk had been nearly absorbed.

This study indicates that initiation of a larval round whitefish field sampling program should take into account temperature (degree days) and perhaps exposure of the sampling area to wave action. Sampling for larvae should be concentrated on or near the bottom over a sand substrate and during daylight.

SUMMARY

1. First hatch of round whitefish larvae from fertilization (December 1, 1981) occurred on day 123 for an average of 298 degree days. Complete hatch occurred on day 131.

2. Sand was the preferred substrate. A stronger attraction for sand occurred when larvae were incubated over other substrates. It is not known whether sand was chosen on the basis of colour and/or particle size.

3. Vision may have been a key sensory mechanism employed by the larvae during selection of a substrate since sand was chosen to the greatest extent under lighted conditions.

4. Round whitefish larvae resided primarily within 10 cm of the bottom in a 135 cm test column. This area was preferred to the greatest extent under lighted conditions.,

ACKNOWLEDGEMENTS

The Region of Durham Works Department and the technicians at the Oshawa Water Supply Station and the Ajax Water Supply Station provided daily temperature data used in this study.

Approved:

D. Harrison
Manager
Chemical Research Department

Submitted:

R.S. McKinley
Unit Head - Biological Services
and Resource Unit
Biological Research Section

RSM:rdm

LITERATURE CITED

1. Brooke, L.T. 1975. Effect of different contant incubation temperatures on egg survival and embryonic development in lake whitefish (*Coregonus dupeaformis*). Trans. Am. Fish. Soc. 104:555-559.

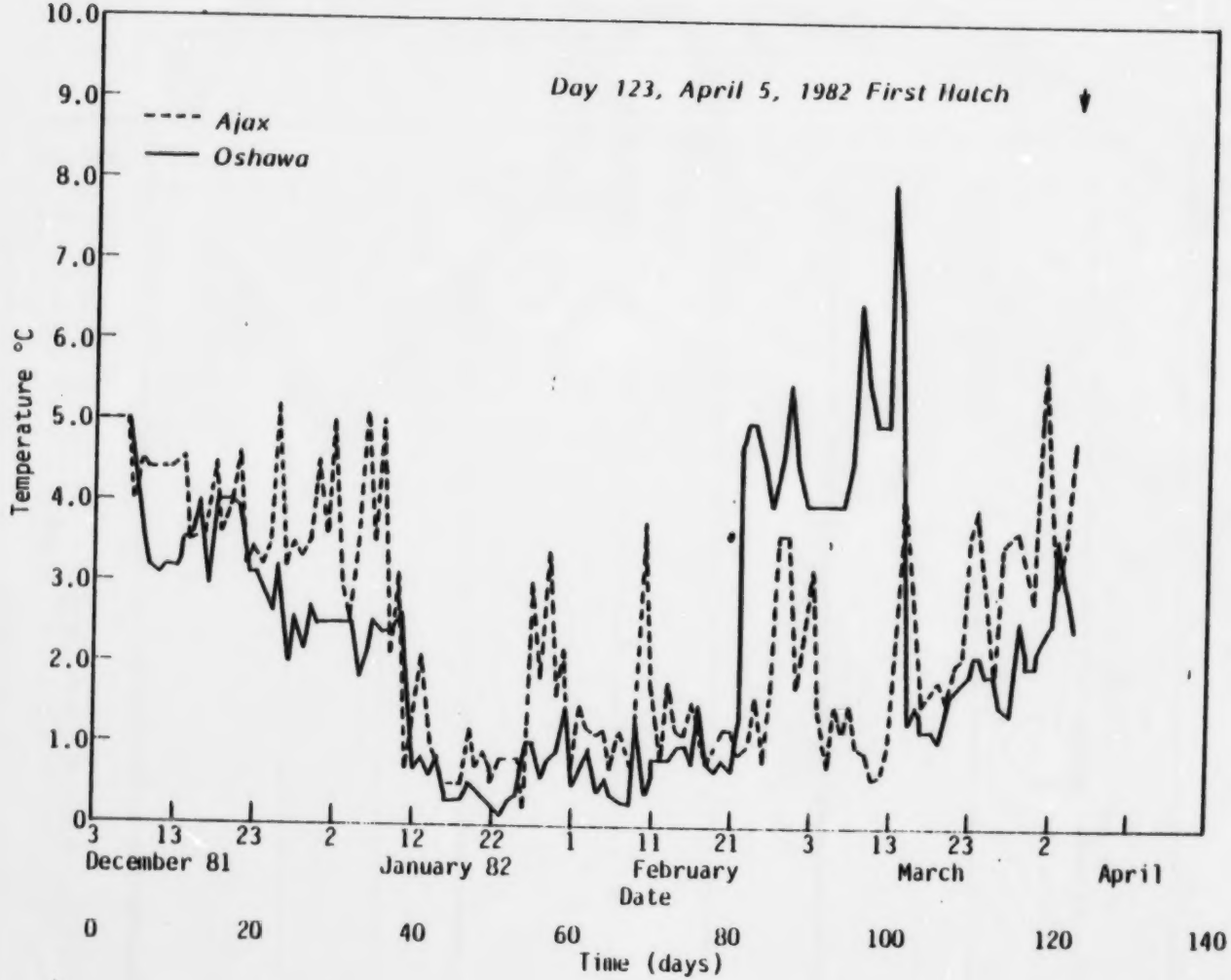
2. Ontario Hydro Research Division Report 76-499-K. "Effects of Constant and Fluctuating Temperatures on the Development Rate and Hatching Success of Yellow Perch Eggs". J.S. Griffiths.

3. Ontario Hydro Research Division Report 79-165-K. "Literature Review of Environmental Characteristics of the North Shore of Lake Ontario". H. Balesic.

4. Ontario Hydro Research Division Report 79-521-K. "Potential Effects of Unstable Thermal Discharges on Incubation of Lake Whitefish Eggs". J.S. Griffiths.

5. Ontario Hydro Research Division Report 80-140-K. "Potential Effects of Unstable Thermal Discharges on Incubation of Round Whitefish Eggs". J.S. Griffiths.

6. Sandy, J.M. and Blaxter, J.H.S. 1980. "A Study of Retinal Development in Larval Herring and Sole". J Mar, Biol Assoc, UK (1980) 60, pp 59-71.



APPENDIX 1

LAKE ONTARIO AMBIENT TEMPERATURES

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APPENDIX 2

ROUND WHITEFISH EGG INCUBATION - LAKE AMBIENT & EXPERIMENTAL TEMPERATURE REGIMES

DATE	DAY	LAKE TEMP AJAX	LAKE TEMP OSHAWA	EXPERIMENTAL TEMP SAND-1	-2	-3	GRAVEL-1	-2	-3	COBBLE-1	-2	-3	DEVEL STAGE	AVG TEMP
1981-12-01		Spawned Dec 1/81 1000 Hrs											From Brooke 1975	
02														5.23
03	0	5.0	5.0											5.23
04		5.0	5.0											4.89
05		5.0	5.0											4.89
06		5.0	5.0										1	4.53
07		5.0	5.0											4.15
08	5	4.0	4.4										1-2	5.39
09		4.5	3.6											4.51
10		4.4	3.2										2-3	5.29
11		4.4	3.1											4.60
12		4.4	3.2											4.60
13	10	4.4	3.2										3-4	3.87
14		4.5	3.5											4.11
15		3.5	3.6										4-5	4.09
16		3.8	4.0											4.79
17		3.6	3.0											3.14
18	15	4.5	4.0											3.11
19		3.6	4.0											3.11
20		3.9	4.0										5	3.08
21		4.6	3.9											3.78
22		3.2	3.1											4.01
23	20	3.4	3.1										5-6	3.70
24		3.2	2.9											3.47
25		3.5	2.6											3.5
26		5.2	3.2											3.40
27		3.2	2.0										7-8	3.20
28	25	3.5	2.6										7-8	2.2
29	26	3.3	2.2	2.0	1.8	2.0		2.3	2.4	2.2	2.2	2.3		2.0
30		3.5	2.7	1.6	1.6	1.6		2.2	2.2	2.3	2.1	2.1		1.9
31		4.5	2.5	1.5	1.6	1.6		2.0	2.0	2.1	2.0	2.0		

APPENDIX 2 (Cont'd)

DATE	DAY	LAKE TEMP AJAX	LAKE TEMP OSHAWA	EXPERIMENTAL TEMP SAND-1	-2	-3	GRAVEL-1	-2	-3	COBBLE-1	-2	-3	DEVEL STAGE	AVG TEMP
1982-01-01		3.6	2.5	[1.5	[1.6	[1.6	[2.0	[2.0	[2.0	[2.1	[2.0	[2.2		
02	30	5.0	2.5	[1.5	[1.6	[1.6	[2.0	[2.0	[2.0	[2.1	[2.0	[2.2		1.9
03		3.0	2.5	[1.4	[1.6	[1.5	[2.0	[2.0	[2.0	[2.2	[2.0	[2.2		1.9
04		2.5	2.5	1.4	1.6	1.5	2.0	2.0	2.1	2.2	2.0	2.3	11	1.9
05		3.5	1.8	1.8	1.5	1.8	2.1	2.1	2.2	2.2	2.1	2.1		2.0
06		5.1	2.1	1.9	1.3	1.6	2.0	2.1	2.1	2.1	1.9	2.1		1.9
07	35	3.5	2.5	2.0	1.4	1.8	2.2	2.3	2.2	2.3	2.3	2.3	11-12	2.1
08		5.0	2.4	1.3	1.4	1.5	1.8	1.9	1.8	1.7	1.6	1.7	12	1.6
09		2.1	2.4	[1.6	[1.6	[1.7	[2.2	[2.3	[2.2	[2.2	[2.1	[2.2		2.0
10		3.1	2.6	[1.6	[1.6	[1.7	[2.2	[2.3	[2.2	[2.2	[2.1	[2.2		2.0
11		0.7	1.4	1.9	1.8	1.9	2.5	2.6	2.6	2.6	2.6	2.6	12-13	2.3
12	40	1.5	0.7	1.4	1.5	1.7	2.0	2.1	2.0	2.0	1.8	2.0		1.8
13		2.1	0.8	1.7	1.7	1.4	1.8	2.0	1.9	1.7	1.7	1.8		1.7
14		1.1	0.6	2.2	2.2	2.1	2.4	2.6	2.5	2.3	2.3	2.3		2.3
15		0.7	0.8	1.9	1.6	1.5	1.2	1.5	1.2	1.2	1.2	1.2	13	1.4
16		0.5	0.3	[1.6	[1.7	[1.3	[1.2	[1.7	[1.2	[1.2	[1.2	[1.2		1.4
17	45	0.5	0.3	[1.6	[1.7	[1.3	[1.3	[1.7	[1.3	[1.2	[1.2	[1.1		1.4
18		0.5	0.3	1.3	1.8	1.1	1.3	1.9	1.3	1.2	1.2	1.1	14-15	1.4
19		1.2	0.5	1.5	1.6	1.7	1.8	1.7	1.8	1.8	1.8	1.7		1.7
20		0.7	0.4	1.4	1.1	1.3	1.1	1.1	1.3	1.1	1.0	1.0	13	1.2
21		0.8	0.3	1.4	1.1	1.2	1.4	1.2	1.4	1.3	1.3	1.2		1.3
22	50	0.5	0.2	2.1	1.9	2.0	2.1	2.1	2.2	2.1	2.1	2.0	14-15	2.1
23		0.8	0.1	[2.0	[1.7	[1.8	[2.4	[2.3	[2.4	[2.4	[2.4	[2.3		2.2
24		0.8	0.3	[1.9	[1.7	[1.8	[2.4	[2.4	[2.5	[2.5	[2.4	[2.4		2.2
25		0.8	0.4	1.8	1.5	1.6	2.7	2.6	2.7	2.8	2.7	2.7	16	2.3
26		0.2	1.0	2.0	1.8	1.8	2.9	2.8	2.9	2.8	2.9	2.7		2.5
27	55	3.0	1.0	1.5	1.3	1.2	1.2	1.3	1.3	1.2	1.1	1.1	16-17	1.2
28		1.8	0.6	1.1	1.1	1.2	1.3	1.3	1.4	1.3	1.3	1.2		1.2
29		3.4	0.8	1.0	1.1	1.2	1.3	1.3	1.3	1.2	1.2	1.2	17	1.2
30		1.6	0.9	[1.0	[1.1	[1.2	[1.3	[1.3	[1.3	[1.2	[1.2	[1.2		1.2
31		2.2	1.5	[1.1	[1.1	[1.3	[1.3	[1.3	[1.3	[1.1	[1.2	[1.1		1.2
1982-02-01	60	0.7	0.5	1.1	1.1	1.3	1.3	1.3	1.3	1.1	1.2	1.1	17	1.2
02		1.5	0.7	1.2	1.3	1.4	1.3	1.3	1.4	1.3	1.3	1.4		1.3
03		1.2	0.9	1.1	1.1	1.4	1.3	1.3	1.2	1.2	1.3	1.3	17-18	1.2
04		1.1	0.4	1.8	1.9	1.8	2.3	2.1	1.8	1.7	2.0	1.8		1.9
05		1.2	0.5	2.1	2.1	2.2	2.2	2.0	2.0	2.1	2.0	2.0	17-18	2.1
06	65	0.7	0.4	[1.9	[1.8	[1.9	[1.9	[1.8	[1.8	[2.0	[1.6	[1.6		1.8
07		1.2	0.3	[1.9	[1.8	[1.9	[1.9	[1.8	[1.8	[2.0	[1.7	[1.7		1.8

APPENDIX 2 (Cont'd)

DATE	DAY	LAKE TEMP AJAX	LAKE TEMP OSHAWA	EXPERIMENTAL TEMP SAND-1	-2	-3	GRAVEL-1	-2	-3	COBBLE-1	-2	-3	DEVEL STAGE	AVG TEMP
1982-02-08		0.8	0.3	1.6	1.5	1.5	1.5	1.5	1.5	1.9	1.3	1.3	17-18	1.5
09		1.5	1.3	1.6	1.5	1.6	1.8	1.7	1.9	1.6	1.6	1.6		1.7
10		3.8	0.3	1.3	1.3	1.3	1.6	1.5	1.4	1.5	1.4	1.5	18	1.4
11	70	1.7	0.8	1.2	1.2	1.2	1.4	1.2	1.4	1.2	1.3	1.3		1.3
12		0.7	0.8	1.3	1.3	1.3	1.5	1.4	1.5	1.2	1.2	1.3	18	1.3
13		1.8	0.8	[1.3	[1.3	[1.3	[1.5	[1.4	[1.5	[1.2	[1.2	[1.3		1.3
14		1.2	1.0	[1.2	[1.2	[1.2	[1.5	[1.3	[1.5	[1.2	[1.1	[1.2		1.3
15		1.1	1.0	1.2	1.2	1.2	1.5	1.3	1.5	1.2	1.1	1.2	18	1.3
16	75	1.5	0.8	1.2	1.2	1.3	1.6	1.5	1.6	1.4	1.5	1.4		1.4
17		1.1	1.5	1.3	1.2	1.3	1.5	1.3	1.6	1.3	1.2	1.3	18	1.3
18		0.8	0.8	1.3	1.3	1.3	1.5	1.4	1.5	1.4	1.3	1.4		1.4
19		1.0	0.7	1.3	1.3	1.3	1.6	1.4	1.4	1.4	1.3	1.4	18	1.5
20		1.2	0.8	[1.3	[1.3	[1.3	[1.7	[1.7	[1.4	[1.4	[1.3	[1.4		1.4
21	80	1.2	0.7	[1.3	[1.2	[1.3	[1.7	[1.7	[1.5	[1.4	[1.4	[1.5		1.4
22		0.9	1.3	1.3	1.2	1.3	1.8	1.9	1.5	1.4	1.4	1.5	18	1.5
23		1.0	5.0	1.6	1.6	1.8	1.8	1.8	1.8	1.9	1.8	1.8		1.8
24		1.6	5.0	1.1	1.1	1.2	1.3	1.3	1.3	1.2	1.2	1.3	18	1.2
25		0.8	4.5	1.1	1.1	1.3	1.2	1.2	1.4	1.3	1.2	1.3		1.2
26	85	1.8	4.0	1.1	1.1	1.3	1.1	1.2	1.3	1.2	1.2	1.3	18	1.2
27		3.6	4.5	[1.1	[1.1	[1.3	[1.2	[1.3	[1.3	[1.2	[1.2	[1.3		1.2
28		3.6	5.5	[1.2	[1.2	[1.4	[1.2	[1.3	[1.4	[1.3	[1.3	[1.3		1.3
1982-03-01		1.7	4.5	1.2	1.2	1.4	1.3	1.4	1.4	1.3	1.3	1.3	18-19	1.3
02		2.0	4.0	1.1	1.1	1.3	1.3	1.4	1.3	1.2	1.2	1.3		1.2
03	90	3.2	4.0	1.1	1.1	1.2	1.3	1.3	1.3	1.2	1.3	1.3	18-19	1.2
04		1.5	4.0	1.1	1.1	1.1	1.3	1.3	1.3	1.2	1.3	1.3	18-19	1.2
05		0.8	4.0	1.1	1.1	1.1	1.3	1.3	1.3	1.2	1.3	1.3		1.2
06		1.5	4.0	[1.1	[1.1	[1.1	[1.3	[1.3	[1.3	[1.4	[1.2	[1.3		1.2
07		1.2	4.0	[1.1	[1.1	[1.1	[1.2	[1.2	[1.2	[1.4	[1.2	[1.2		1.2
08	95	1.5	4.5	1.1	1.1	1.1	1.2	1.2	1.2	1.6	1.1	1.2	18-19	1.2
09		1.0	6.5	1.2	1.2	1.1	1.2	1.2	1.3	1.2	1.2	1.3		1.2
10		0.9	5.5	1.7	1.7	1.6	1.8	1.5	1.7	1.8	1.7	1.8		1.8
11		0.6	5.0	1.4	1.5	1.4	1.6	1.4	1.4	1.6	1.5	1.6	18-19	1.5
12		0.7	5.0	1.3	1.3	1.4	1.5	1.3	1.3	1.3	1.4	1.4		1.4
13	100	1.0	8.0	[1.2	[1.2	[1.3	[1.4	[1.3	[1.3	[1.3	[1.3	[1.4		1.3
14		2.6	6.5	[1.2	[1.2	[1.3	[1.4	[1.2	[1.3	[1.2	[1.3	[1.3		1.3
15		4.1	1.3	1.1	1.0	1.1	1.2	1.2	1.3	1.2	1.2	1.3	19	1.2

APPENDIX 2 (Cont'd)

DATE	DAY	LAKE TEMP AJAX	LAKE TEMP OSHAWA	EXPERIMENTAL TEMP SAND-1	SAND-2	SAND-3	GRAVEL-1	GRAVEL-2	GRAVEL-3	COBBLE-1	COBBLE-2	COBBLE-3	DEVEL STAGE	AVG TEMP
1982-03-16		2.5	1.5	1.3	1.2	1.3	1.2	1.2	1.3	1.2	1.2	1.2		1.2
17		1.5	1.2	1.4	1.4	1.5	1.2	1.3	1.8	1.3	1.3	1.5	19	1.4
18	105	1.6	1.2	1.8	1.7	1.7	1.1	1.1	1.2	1.3	1.3	1.2	19-20	1.4
19		1.8	1.1	1.8	1.2	1.2	1.2	1.1	1.1	1.2	1.1	1.3		1.2
20		1.5	1.4	[1.8	[1.3	[1.4	[1.3	[1.3	[1.3	[1.3	[1.3	[1.4		1.4
21		2.0	1.7	[1.8	[1.3	[1.4	[1.3	[1.3	[1.3	[1.4	[1.3	[1.4		1.4
22		2.1	1.8	1.8	1.4	1.5	1.5	1.4	1.4	1.5	1.5	1.5	19-20	1.5
23	110	3.5	1.9	1.4	1.3	1.4	1.3	1.3	1.3	1.4	1.3	1.4		1.3
24		4.0	2.1	1.3	1.2	1.3	1.3	1.2	1.1	1.2	1.3	1.3	19-20	1.2
25		2.8	1.9	3.8	3.8	4.0	4.2	4.2	4.1	4.3	4.4	4.5		4.1
26		1.9	1.9	3.6	3.6	3.6	3.9	3.9	3.6	3.8	4.1	3.8		3.8
27		3.4	1.5	[3.6	[3.6	[3.6	[3.8	[3.8	[3.6	[3.8	[4.1	[3.8		3.8
28	115	3.6	1.4	[3.7	[3.7	[3.7	[3.8	[3.7	[3.7	[3.8	[4.1	[3.7		3.8
29		3.7	2.5	3.7	3.7	3.7	3.7	3.6	3.7	3.8	4.1	3.7	19-20	3.7
30		3.2	2.0	5.4	5.3	5.4	5.9	5.8	5.6	6.0	7.0	8.0		6.0
31		2.8	2.0	5.4	5.4	5.4	5.6	5.5	5.5	5.7	5.6	5.8		5.5
1982-04-01		5.8	2.3	5.1	5.1	5.1	5.1	5.1	5.1	5.2	5.1	6.0		5.2
02	120	4.1	2.5	5.4	5.5	5.4	5.4	5.4	5.4	5.7	5.1	6.4	19-20	5.5
03		3.0	3.6	[5.5	[5.5	[5.5	[5.5	[5.5	[5.5	[5.7	[5.4	[6.1		5.6
04		3.6	3.0	[5.5	[5.6	[5.5	[5.5	[5.5	[5.5	[5.7	[5.4	[6.1		5.6
05	123	4.8	2.5	5.6	5.6	5.6	5.6	5.6	5.6	5.7	5.7	5.8	20	5.7
	Total Degree Days	360.0	291.5											
	Average o Days	298.8			281.9			298.7			297.8			

[Denotes weekend temperatures - mean of Friday and Monday temperatures.]

APPENDIX 3

ROUND WHITEFISH DEVELOPMENTAL STAGES (FROM BROOKE, 1975)

	Stage	Description
↑	1	Blastoderm enveloping upper 1/3 of yolk
	2	Blastoderm enveloping upper 1/2 of yolk
	3	Blastoderm enveloping upper 2/3 of yolk
	4	Embyonic streak formed, yolk plug large
Block 1	5	Optic primordia present, yolk plug small
	6	Embryo extending 1/2 distance round curvature of yolk
	7	Optic cup two-layered, with lens primordium
	8	Tail beginning to be undercut by tail fold
↓	9	Embryo extending 2/3 distance around curvature of yolk
↑	10	Tail curved, body movements visible
	11	Eye pigment first visible
	12	Eye pigment readily visible without magnification, pectoral fin buds present
	13	Pectoral fin clearly formed
Block 2	14	Circulation visible in branch of vitelline vein lateral to heart or yolk
	15	Caudal lobe on tail, yolk with one or two large oil globules
	16	Stellate chromatophores in double row along entire length of body, except head
	17	Pectoral fins spear shaped, fin movements visible
	18	Stellate chromatophores on head
↓	19	Constant pectoral fin flutter
↑ Block 3 ↓	20	Eye movement, hatching

APPENDIX 4

LARVAL RIVER WHITEFISH - SUBSTRATE PREFERENCE

Tank 1
Sand Incubated

Date	Time	Temp	# Larvae Resting On Each Substrate: Sand Fry	Sand Eggs	Gravel Fry	Gravel Eggs	Cobble Fry	Cobble Eggs	# Larvae Swimming
		°C							
82-04-07	1200	9.0	16	23	1	17	6	9	46
	1500		26	27	15	11	2	9	48
82-04-08	0530	8.3	14	23	5	23	3	9	71
	1000		17	21	11	21	9	7	62
	2030	7.4	11	15	14	16	7	5	82
82-04-09	0550	7.3	14	11	9	11	5	5	95
	1025	7.5	25	5	4	10	3	4	99
	2115	7.2	14	5	6	6	7	4	108
82-04-10	1100	8.2	26		8	6	9	7	94
	2000	7.5	10	3	5	6	2	0	126
82-04-11	0540	7.7	15	3	5	6	4	0	119
	1045	7.7	14	3	6	6	5	0	98
	2300	8.0	19	3	5	6	6	0	111
82-04-12	0500	8.0	19	3	5	5	4	0	116
	1200	8.0	17	3	5	3	5		91
	2200	7.9	19	3	6	3	9	0	112
82-04-13	0515	8.1	19	0	10	3	4	0	116
	1230	10.0	46	0	9	3	2	0	95
	2005	8.5	26		7		7		110
82-04-14	0520	8.9	19		17		3		111
	1200		38		10		4		78
	2000	8.4	16		11		5		110
82-04-15	0520		19		6		3		124
	1200	9.3	15		7		6		102
	1930	9.2	20		10		4		116

Tank 2
Gravel Incubated

Temp	# Larvae Resting On Each Substrate: Sand Fry	Sand Eggs	Gravel Fry	Gravel Eggs	Cobble Fry	Cobble Eggs	# Larvae Swimming
9.0	39	4	10	8	4		60
	27	4	11	6	4	7	91
7.9	14	3	3	6	3	3	117
	24	3	10	5	2	4	100
7.4	14	2	11	3	10	3	77
7.4	40	3	5	3	6	2	93
7.0	60	3	6	2	3	3	77
7.4	39	3	7	3	3	3	98
7.6	34	3	2	3	3	3	88
7.6	40	3	0	3	3	3	106
7.8	49	3	3	3	3	3	96
7.9	42	3	3	3	2	3	82
8.1	28	3	10	3	2	3	87
8.1	32	3	9	3	0	3	98
8.2	19	3	3	3	0	3	107
8.3	24	0	9	3	4	3	111
8.1	19	0	10	0	3	0	98
8.6	15		9		3		105
9.3	40		3		10		85
9.1	46		11		4		87
	26		4		3		97
9.1	19		3		2		106
	14		3		4		111
9.8	10		2		3		117
9.7	16		2		2		106

Tank 3
Cobble Incubated

Temp	# Larvae Resting On Each Substrate: Sand Fry	Sand Eggs	Gravel Fry	Gravel Eggs	Cobble Fry	Cobble Eggs	# Larvae Swimming
10.0	22	18	6	11	2	17	32
	11	18	3	12	3	17	41
9.3	22	15	2	19	3	10	58
	23	18	2	19	6	10	47
7.8	13	10	4	10	6	10	60
7.7	23	8	6	17	3	24	67
7.6	42	2	3	11	3	12	67
7.2	25	0	0	12	2	4	100
7.8	15	0	10	3	3	3	86
7.8	15	0	3	6	2	2	108
9.4	41	0	2	6	2	2	90
9.3	67	0	3	3	2	2	69
8.2	46	0	14	2	2	2	84
9.4	15	0	3	2	3	3	101
8.6	41	0	8	2	4	3	54
8.9	23	0	12	2	3	0	108
9.3	18	0	6	0	4	0	102
9.9	41		11		3		90
9.2	26		6		3		111
8.9	39		4		3		84
	27		3		3		65
9.0	14		6		3		105
	12		3		4		87
9.3	17		6		3		96
9.1	41		4		3		99

Tank 4
Control

Temp	# Larvae Resting On Each Substrate: Sand Fry	Sand Eggs	Gravel Fry	Gravel Eggs	Cobble Fry	Cobble Eggs	# Larvae Swimming
9.5	0	50	0	50	0	50	0
	0	50	0	50	0	50	0
8.3	0	50	0	50	0	50	0
	0	50	0	50	0	50	0
7.5	0	50	0	50	0	50	0
7.8	0	50	0	50	0	50	0
7.7	0	50	0	50	0	50	0
7.6	0	50	0	50	0	50	0
8.6	0	50	0	50	0	50	0
8.0	0	50	0	50	0	50	0
8.4	0	50	0	50	0	50	0
8.5	0	50	0	50	0	50	0
9.0	0	50	0	50	0	50	0
8.6	0	50	0	50	0	50	0
8.7	0	50	0	50	0	50	0
9.1	1	41	0	45	0	4	11
9.4	5	30	2	47	0	30	42
9.1	41	26	5	42	1	28	39
9.5	1	24	1	38	0	22	64
9.5	17	17	2	26	1	22	65
	21	1	2	22	1	16	71
9.6	5	17	1	22	0	16	87
	29		2	30	2	9	84
9.9	28	9	4	10	1	7	91
10.4	5	9	1	3	0	6	122

APPENDIX A (Cont'd)

Tank 1						Tank 2					Tank 3					Tank 4				
			# Larvae Resting On Each Substrate		# Larvae Swimming		# Larvae Resting On Each Substrate		# Larvae Swimming		# Larvae Resting On Each Substrate		# Larvae Swimming		# Larvae Resting On Each Substrate			# Larvae Swimming
Date	Time	Temp	Sand	Gravel	Cobble		Temp	Sand	Gravel	Cobble		Temp	Sand	Gravel	Cobble		Temp	Sand	Gravel	Cobble	
82-04-16	0520		22	9	5	111		24	6	2	119		43	8	5	96		19	1	1	1	0	2	124
	1155	10.1	13	5	2	130	9.4	16	0	0	130	9.6	26	4	1	119	10.1	37	0	4	1	3	1	104
82-04-17	1200	14.0	18	5	4	121	14.0	27	1	2	115	14.0	32	1	1	112	14.0	50	0	2	0	0	0	97
82-04-19	0530	10.2	22	5	3	120	9.5	42	0	1	107	9.9	49	8	5	88	10.5	48	0	2	0	2	0	98
	1200		19	6	2	121		48	1	2	110		29	1	1	115		65		6		5		78
	1720	7.6	18	5	7	120	8.0	48	6	4	112	7.8	50	11	4	103	8.5	36		5		5		106
82-04-20	1145		51	21	2	74		61	4	1	82		74	11	8	57		109		12		1		28
	2200	7.8	22	12	4	112	8.2	59	6	9	96	8.4	80	11	11	90	8.8	36		13		10		91
82-04-21	0520	8.2	17	8	1	102	8.8	67	7	7	89	8.5	55	7	1	87	8.9	80		9		1		60
	1845		45	15	10	80		76	2	5	97		78	15	14	61		115		1		6		24
	2140	8.0	17	16	8	99	8.1	57	6	5	94	8.4	27	15	11	97	8.8	38		14		5		91
82-04-22	0530	8.7	20	15	8	107	10.2	67	16	8	79	8.5	58	6	7	79	9.1	66		14		5		63
	1200		40	20	10	74		64	7	4	79		95	10	14	11		105		11		4		28
	2000	7.0	24	9	4	111	7.4	42	5	2	108	7.5	11	15	11	91	8.5	28		11		2		107
82-04-23	0630	8.5	46	18	6	92		71	1	2	2		60	4	1	1		82		9		5		54
	1130	9.4	11	5	2	112		29	1	1	117		41	4	0	101		82		10		11		37
	2330		41	19	7	91		68	1	5	91		68	8	2	80		76		6		12		90

APPENDIX 5

LARVAL ROUND WHITEFISH DEPTH PREFERENCE

Difference between number observed and number of eggs would approximate number of dead.

Date	Time	Depth, cm #Fry Bottom	0-45	45-90	90-135	# Eggs
82-04-07	1200	All Eggs	-	-	-	50
82-04-13	0515					
	1230	1	-	-	2	47
	2005	2	-	-	2	46
82-04-14	1200	-	4	-	1	45
	2000	-	1	-	2	45
82-04-15	0520	3	3	-	1	40
	1200	3	4	-	1	40
	1950	-	3	-	1	40
82-04-16	0520	9	-	-	1	30
	1155	1	3	2	1	30
82-04-17	1200	-	-	-	1	30
82-04-19	0530	6	-	-	1	28
	1200	9	-	-	1	25
82-04-20	0520	12	-	-	1	20
	1145	14	1	-	-	20
82-04-21	0520	12	-	-	1	13
	1145	11	-	-	-	13
82-04-22	0530	15	-	-	1	0
	1200	9	5	-	2	
82-04-23	0630	12	-	-	1	
	1130	19	1	-	1	
	2330	18	-	1	1	
82-04-28	1130	21	-	-	-	
82-04-29	1130	19	-	1	-	
82-04-30	1130	28	1	1	-	

APPENDIX 6

LARVAL ROUND WHITEFISH DEVELOPMENT

Length (mm)	Time After Hatch (hrs)	
14 (n=2)	1-2 Immediate Post Hatch	Median finfold undifferentiated; chromatophores on dorsal aspect of head and back (body), on yolk-sac and laterally along body just above the intenstinal tract; yolk-sac full and robust.
15 (n=8)	24	Yolk-sac less robust and more ovoid in shape, chromatophores as previous; median finfold differentiating along dorsal aspect.
15.5 (n=11)	40	Pectoral finbuds well developed; median finfold differentiation more evident; yolk-sac reducing in size (streamlined).
16 (n=6)	60	Similar to previous.
16 (n=8)	108	Similar to previous.
16 (n=10)	132	Yolk-sac completely absorbed or nearly so; median finfold well differentiated; fin rays absent.
16 (n=6)	156	Yolk-sac more streamlined.
16 (n=5)	228	Similar to previous.
16 (n=7)	252	First appearance of pelvic fin buds.
16 (n=8)	276	Same as above.
16.5 (n=9)	300	Pelvic fin buds show slight development.
16.5 (n=6)	324	Same as above.

POOR

QUALITY

ORIGINAL